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RESEARCH MEMORANDUM

FLIGHT MEASUREMENTS WITH THE DOUGLAS D-558-II (BUAERO NO. 37974) RESEARCH AIRPLANE

MEASUREMENTS OF THE BUFFET BOUNDARY AND PEAK AIRPLANE NORMAL-FORCE COEFFICIENTS AT MACH NUMBERS UP TO 0.90

By John P. Mayer and George M. Valentine

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Measurements have been made of the buffet boundary and peak normal-force coefficients for the Douglas D-558-II airplane up to a Mach number of 0.90. These measurements indicate that the buffet boundary falls considerably below the maximum normal-force coefficients in the Mach number range covered in these tests. The normal-force coefficient at which buffeting starts decreases gradually from a normal-force coefficient of about 0.84 at a Mach number of 0.30 to a normal-force coefficient of 0.5 at a Mach number of 0.80. The normal-force coefficient at which buffeting starts then decreases rapidly to a normal-force coefficient of 0.1 at a Mach number of 0.88. Buffeting magnitudes for the D-558-II airplane have been very mild just beyond the buffet boundary above a Mach number of 0.80, however, and pilots have reported no buffeting below a normal-force coefficient of 0.4 in this number range.

The maximum airplane normal-force coefficients reached with the airplane in the clean condition were $C_{N_A} = 1.46$ with the slats unlocked at a Mach number of 0.29 and $C_{N_A} = 1.25$ with the slats locked at a Mach number of 0.55. In general, the variation of the absolute maximum normal-force coefficient with Mach number was not determined because of the longitudinal instability of the D-558-II airplane at high normal-force coefficients.

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INTRODUCTION

As a part of the cooperative NACA-Navy Transonic Flight Research Program, the NACA is utilizing the Douglas D-558-II research airplane for flight investigations at the NACA High-Speed Flight Research Station, Edwards Air Force Base, Muroc, Calif.

As a part of the flight investigations it was desired to obtain the variation of the maximum normal-force coefficient and the normal-force coefficient at which buffeting started with Mach number; however, it was found that the D-558-II airplane was longitudinally unstable at high normal-force coefficients (reference 1) and, therefore, it was not advisable to completely stall the airplane and reach the absolute maximum normal-force coefficient. This paper presents the results from measurements of the buffet boundary and the peak normal-force coefficients reached with the D-558-II airplane in the Mach number range from 0.26 to 0.90. The peak normal-force coefficients presented are the highest normal-force coefficients reached in the present tests and in general are not the absolute maximum normal-force coefficients.

Results on other characteristics of the D-558-II airplane are presented in references 1 and 2.

SYMBOLS

n	airplane normal load factor, g units
W	airplane gross weight, pounds
q	free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
S_W	wing area, square feet
C_{N_A}	airplane normal-force coefficient $\left(\frac{nW}{qS_W}\right)$
V	free-stream velocity, feet per second
a	velocity of sound, feet per second
M	Mach number (V/a)
α_A	airplane angle of attack (measured with respect to airplane center line), degrees

ρ	mass density, slugs per cubic foot
μ	coefficient of viscosity, slugs per foot-second
$\bar{c}$	wing mean aerodynamic chord, feet
R	Reynolds number (based on standard atmosphere) $\left(\frac{\rho V \bar{c}}{\mu}\right)$
g	acceleration due to gravity, feet per second per second

AIRPLANE

The Douglas D-558-II airplanes have sweptback wing and tail surfaces and were designed for combination turbojet and rocket power plant. The airplane being used in the present investigation (BuAero No. 37974) does not yet have the rocket engine installed. This airplane is powered only by a J-34-WE-40 turbojet engine which exhausts from the bottom of the fuselage between the wing and the tail. Both slats and stall-control vanes are incorporated on the wing of the airplane. The wing slats can be locked in the closed position or they can be unlocked. When the slats are unlocked, the slat position is a function of the angle of attack of the airplane. The airplane is equipped with an adjustable stabilizer. Photographs of the airplane are shown in figures 1 and 2 and a three-view drawing is shown in figure 3. A drawing of the wing section showing the wing slat in the closed and extended positions is given in figure 4. Pertinent airplane dimensions and characteristics are listed in table I.

INSTRUMENTATION AND ACCURACY

Standard NACA recording instruments were installed in the airplane to measure the following quantities:

Airspeed
Altitude
Elevator and aileron wheel forces
Rudder pedal force
Normal, longitudinal, and transverse accelerations at the center of gravity of the airplane
Pitching, rolling, and yawing velocities
Airplane angle of attack
Stabilizer, elevator, rudder, aileron, and slat positions

Strain gages were installed on the airplane structure to measure wing and tail loads. Strain-gage deflections were measured with a recording oscillograph.

A free-swiveling airspeed head was used to measure both static and impact pressures. This airspeed head was mounted on a boom approximately 7 feet forward of the nose of the airplane. The vane which was used to measure angle of attack was mounted on the same boom approximately $4\frac{1}{2}$ feet forward of the nose of the airplane.

The airspeed system was calibrated for position error by the "fly-by" method at low lift coefficients up to a Mach number of 0.70. The swiveling airspeed head used on the airplane was calibrated in a wind tunnel for instrument error up to a Mach number of 0.85. Tests of similar nose-boom installations indicate that the position error does not vary with Mach number up to a Mach number of 0.90. By combining the constant position error of the fuselage with the error due to the airspeed head, the calibration was extended to a Mach number of 0.85. At Mach numbers between 0.85 and 0.90 the calibration was extrapolated.

The angle-of-attack vane was not calibrated for position error in flight. However, estimated errors in angle of attack due to position error, boom bending, and pitching velocity were small. No corrections have been made to the angles of attack presented in this paper.

The estimated accuracies of the pertinent parameters used in determining the airplane buffet boundaries and peak normal-force coefficients are as follows:

M	±0.01
C_{N_A}	±0.02
α_A, degrees	±1

However, because of the uncertainty in determining the point where buffeting starts from the flight records, the estimated accuracies for the buffet boundary are approximately:

M	±0.02
C_{N_A}	±0.05

TESTS

All the data presented were obtained with the airplane in the clean condition and with power on. Data are presented for both slats-locked and slats-unlocked configurations. Buffet boundaries and peak normal-force coefficients obtained were found in 1 g stall approaches and in turns at Mach numbers from 0.26 to 0.90 and at altitudes from 10,000 feet to 25,000 feet. The Reynolds number varied from 8×10^6 to 32×10^6. The range of Reynolds number and Mach number for which data are presented is shown in figure 5.

In the course of the flight tests of the present airplane it was found that the trailing edge of the wing slats deflected upward in flight with the slats locked. It is not known at this time what effect this slat deflection has on the airplane buffet boundary or maximum normal-force coefficient.

RESULTS AND DISCUSSION

Airplane Lift Curves

Typical variations of the airplane normal-force coefficient with airplane angle of attack are shown in figures 6 and 7. Presented in figure 6 is the variation of the airplane normal-force coefficient with airplane angle of attack for the slats-unlocked condition. For this particular case, buffeting started at an angle of attack of approximately 10° and a normal-force coefficient of about 0.85. The slat is almost fully open at this point. The normal-force coefficient increases with angle of attack to an angle of approximately 24° and then remains almost constant at angles of attack to 32°. The normal-force coefficient then increases and reaches a peak of 1.46 at an angle of attack of approximately 36°.

The variation of the normal-force coefficient with angle of attack for the slats-closed condition is shown in figure 7. Buffeting starts at an angle of attack of about 8° and a normal-force coefficient of approximately 0.77 for this case. The normal-force coefficient varies linearly with angle of attack up to an angle of attack of 9°. The slope then decreases and a peak normal-force coefficient of 1.11 is reached at an angle of attack of approximately 23°.

Buffet Boundary

The buffet boundary for the D-558-II airplane is shown in figure 8. This boundary is defined by the normal-force coefficient and Mach number at which a definite buffet starts as the airplane normal-force coefficient is increased and, in general, the buffeting of the wing and tail is caused by flow separation on the wing. The buffet boundary for the airplane was determined by examining records of the recording airplane accelerometer and strain-gage records of the wing and tail loads. Photographs of typical accelerometer and strain-gage flight records of a 1 g stall approach, a low-speed turn, and a high-speed turn, are shown in figures 9(a), 9(b), and 9(c), respectively. The start of buffeting was determined from the instrument records such as those presented in figure 9 as that point on the record where the amplitude increases as the normal-force coefficient increased. For example, it may be seen in figure 9(a) that buffeting starts at approximately 0.5 second. This point corresponds to an angle of attack of about 10° as shown in figure 6 and to a point on the buffet boundary at a Mach number of approximately 0.4 and a normal-force coefficient of about 0.85. A similar evaluation was made throughout the Mach number range for various maneuvers such as those shown in figures 9(b) and 9(c). The boundary established, therefore, separates the region of relatively smooth flight from the region where buffeting is present.

For the slats-locked configuration, the normal-force coefficient at which buffeting starts is shown in figure 8 to decrease gradually with Mach number up to a Mach number of 0.83. From a Mach number of 0.83 to 0.90 the normal-force coefficient at which buffeting starts decreases rapidly with Mach number. It may be seen that there are several buffeting points at a Mach number of 0.83 and an airplane normal-force coefficient of 0.10. Intermittent mild buffeting has occurred at this condition on all flights where this Mach number and normal-force coefficient have been encountered. This buffeting did not occur at higher normal-force coefficients, however, or at higher Mach numbers until the buffet boundary was reached. The D-558-II airplane has not gone beyond the buffet boundary to any extent above a Mach number of 0.80 because of the speed limitations of the airplane with only the jet engine operating.

With the wing slats unlocked, it may be seen in figure 8 that the normal-force coefficient at which buffeting starts is about the same as the slats-locked configuration at a Mach number of about 0.3. As the Mach number increases to 0.56 the normal-force coefficient at which buffeting begins decreases more gradually than for the slats-locked condition, and at a Mach number of 0.56 the slats-unlocked boundary is at a normal-force coefficient about 0.2 higher than that of the slats-closed boundary. For most of the test points shown on the slats-unlocked buffet boundary the slats were almost fully extended when buffeting started (for example, see fig. 6).

During one maneuver with the D-558-II airplane, the airplane entered a buffeting region at a negative normal-force coefficient. As a matter of interest, this negative buffet boundary point is shown in figure 8 at a Mach number of 0.51 and an airplane normal-force coefficient of -0.64 and, for convenience, is plotted as a positive normal-force coefficient. It may be seen that the negative buffet boundary point coincides with the positive buffet boundary for this particular case. The maneuver in which this point was obtained, however, was a violent maneuver and there were some conditions such as abrupt pitching and yawing which might have affected the buffet boundary.

In order to compare the buffet boundary as determined from pilot's impressions and that established by means of recording strain-gage and accelerometer measurements, a push-button switch was installed on the control wheel of the airplane so that the pilot could indicate when he felt the buffeting start. Shown in figure 10 are comparisons of the points at which the pilot indicated buffeting started with the buffet boundary as established from recording strain-gage and accelerometer measurements. In general, it may be seen in figure 10 that the buffet boundary determined from the pilot's impressions is in fairly good agreement with the boundary established from recorded measurements at Mach numbers up to 0.70. In the Mach number range from 0.83 to 0.90, however, pilots have not reported any buffeting below a normal-force coefficient of about 0.4.

Maximum Normal-Force Coefficients

The highest normal-force coefficients reached in the tests of the D-558-II airplane thus far are shown in figure 11. Because of the longitudinal instability of the airplane mentioned previously, it has not been advisable to completely stall the airplane. Therefore, the peak values of the airplane normal-force coefficient shown in figure 11 are, for the most part, not the absolute maximum normal-force coefficients. The highest airplane normal-force coefficient reached with the slats locked was 1.25 at a Mach number of 0.55. This normal-force coefficient was reached in a turn in which the airplane pitched up abruptly and inadvertently snap rolled. It was during this maneuver that the negative buffet boundary point of figure 8 was also obtained. With the slats unlocked, a peak normal-force coefficient of 1.46 was obtained at an angle of attack of about 36° and a Mach number of 0.29. (See fig. 6.) It is believed that the absolute value of the maximum normal-force coefficient might have been reached in this run since the airplane normal-force coefficient decreased as the angle of attack increased to 40°.

Comparisons

A comparison between the maximum normal-force coefficients and buffet boundaries for the unswept-wing Bell X-1 airplane (references 3 and 4) and the peak normal-force coefficients and buffet boundary for the swept-wing D-558-II airplane is shown in figure 12. (It may be added that the straight-wing D-558-I research airplane had approximately the same buffet boundaries as the X-1 airplane. These airplanes both have NACA 65-110 airfoil sections and the buffet-boundary measurements were made in the same manner as were the measurements on the D-558-II airplane.) Below a Mach number of about 0.72, for the X-1 airplane, buffeting occurs very close to the maximum normal-force coefficient and no distinction is made between the two in fairing a boundary. Above a Mach number of 0.72, for the X-1 airplane, buffeting occurs below the maximum normal-force coefficient. For the swept-wing D-558-II airplane, buffeting occurs before the maximum normal-force coefficient is reached throughout the Mach number range covered. Below a Mach number of 0.8 the D-558-II buffet boundary is below the maximum normal-force coefficient buffet boundary for the X-1 airplane. The maximum normal-force coefficients for the D-558-II airplane are higher than those for the X-1 airplane at Mach numbers up to 0.6. The large normal-force coefficient range between the buffet boundary and the maximum normal-force coefficients for the D-558-II at low Mach numbers is characteristic of some sweptback-wing airplanes where flow separation causes buffeting before the maximum normal-force coefficient is reached. At Mach numbers greater than 0.8, the buffet boundaries for the D-558-II and the X-1 airplanes are approximately the same. It is possible that the similarity of buffet boundaries for the swept- and unswept-wing airplanes above a Mach number of 0.8 is caused by flow separation near the wing root on the swept-wing airplane since, at this point, the flow conditions on both swept and unswept wings may be similar. The buffeting magnitudes for the D-558-II airplane, however, have been very mild just beyond the boundary in this Mach number range and pilots have reported no buffeting in 1 g flights up to a Mach number of 0.90. In addition, the effect of the leading-edge-slat deflection on the buffet boundary is not yet known. A true comparison between the buffet boundaries for unswept- and swept-wing airplanes is not yet possible since the buffeting intensities have not been determined for the D-558-II airplane.

It is of interest to note that the data for buffet boundary and maximum normal-force coefficient for the D-558-II airplane were found to be in essential agreement with British data for a 35° swept-wing airplane in the speed range common to the two sets of tests.

CONCLUDING REMARKS

Measurements have been made of the buffet boundary and peak normal-force coefficients for the D-558-II airplane up to a Mach number of 0.90. These measurements indicate that the buffet boundary falls considerably below the maximum normal-force coefficients in the Mach number range covered in these tests. The normal-force coefficient at which buffeting starts decreases gradually from a normal-force coefficient of about 0.84 at a Mach number of 0.30 to a normal-force coefficient of 0.5 at a Mach number of 0.80. The normal-force coefficient at which buffeting starts then decreases rapidly to a normal-force coefficient of 0.1 at a Mach number of 0.88. Buffeting magnitudes for the D-558-II airplane have been very mild just beyond the boundary above a Mach number of 0.80, however, and pilots have reported no buffeting below a normal-force coefficient of 0.4 in this Mach number range.

The highest airplane normal-force coefficients reached with the airplane in the clean condition were 1.46 with the slats unlocked at a Mach number of 0.29 and 1.25 with the slats locked at a Mach number of 0.55. In general, the variation of the absolute maximum normal-force coefficient with Mach number could not be determined because of the longitudinal instability of the D-558-II airplane at high normal-force coefficients.

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1. Sjoberg, S. A., and Champine, R. A.: Preliminary Flight Measurements of the Static Longitudinal Stability and Stalling Characteristics of the Douglas D-558-II Research Airplane (BuAero No. 37974). NACA RM L9H31a, 1949.

2. Sjoberg, S. A.: Flight Measurements with the Douglas D-558-II (BuAero No. 37974) Research Airplane. Static Lateral and Directional Stability Characteristics as Measured in Sideslips at Mach Numbers up to 0.87. NACA RM L50C14, 1950.

3. Beeler, De E., and Mayer, John P.: Measurements of the Wing and Tail Loads During the Acceptance Tests of the Bell XS-1 Research Airplane. NACA RM L7L12, 1948.

4. Drake, Hubert M., McLaughlin, Milton D., and Goodman, Harold R.: Results Obtained During Accelerated Transonic Tests of the Bell XS-1 Airplane in Flights to a Mach Number of 0.92. NACA RM L8A05a, 1948.

TABLE I

DIMENSIONS AND CHARACTERISTICS OF THE

DOUGLAS D-558-II AIRPLANE

Wing:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63-012
Total area, sq ft	175.0
Span, ft	25.0
Mean aerodynamic chord, in.	87.301
Root chord (parallel to plane of symmetry), in.	108.508
Tip chord (parallel to plane of symmetry), in.	61.180
Taper ratio	0.565
Aspect ratio	3.570
Sweep at 0.30 chord, deg	35.0
Incidence at fuselage center line, deg	3.0
Dihedral, deg	-3.0
Geometric twist, deg	0
Total aileron area (rearward of hinge), sq ft	9.8
Aileron travel (each), deg	±15
Total flap area, sq ft	12.58
Flap travel, deg	50
Horizontal tail:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63-010
Area (including fuselage), sq ft	39.9
Span, in.	143.6
Mean aerodynamic chord, in.	41.75
Root chord (parallel to plane of symmetry), in.	53.6
Tip chord (parallel to plane of symmetry), in.	26.8
Taper ratio	0.50
Aspect ratio	3.59
Sweep at 0.30 chord line, deg	40.0
Dihedral, deg	0
Elevator area, sq ft	9.4
Elevator travel, deg	25 up 15 down
Stabilizer travel, deg	4 L.E. up 5 L.E. down

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TABLE I

DIMENSIONS AND CHARACTERISTICS OF THE

DOUGLAS D-558-II AIRPLANE - Concluded

Vertical tail:	
Airfoil section (parallel to fuselage center line) . . .	NACA 63-010
Area, sq ft	36.6
Height from fuselage center line, in.	98.0
Root chord (parallel to fuselage center line), in.	146.0
Tip chord (parallel to fuselage center line), in.	44.0
Sweep angle at 0.30 chord, deg	49.0
Rudder area (rearward of hinge line), sq ft	6.15
Rudder travel, deg.	±25
Fuselage:	
Length, ft	42.0
Maximum diameter, in.	60.0
Fineness ratio	8.40
Speed-retarder area, sq ft	5.25
Power plant	J-34-WE-40 2 jatos for take-off
Airplane weight (full fuel), lb	10,645
Airplane weight (no fuel) lb	9,085
Airplane weight (full fuel and 2 jatos), lb	11,060
Center-of-gravity locations:	
Full fuel (gear down), percent mean aerodynamic chord . . .	25.3
Full fuel (gear up), percent mean aerodynamic chord	25.8
No fuel (gear down), percent mean aerodynamic chord	26.8
No fuel (gear up), percent mean aerodynamic chord	27.5
Full fuel and 2 jatos (gear down), percent mean aerodynamic chord	29.2

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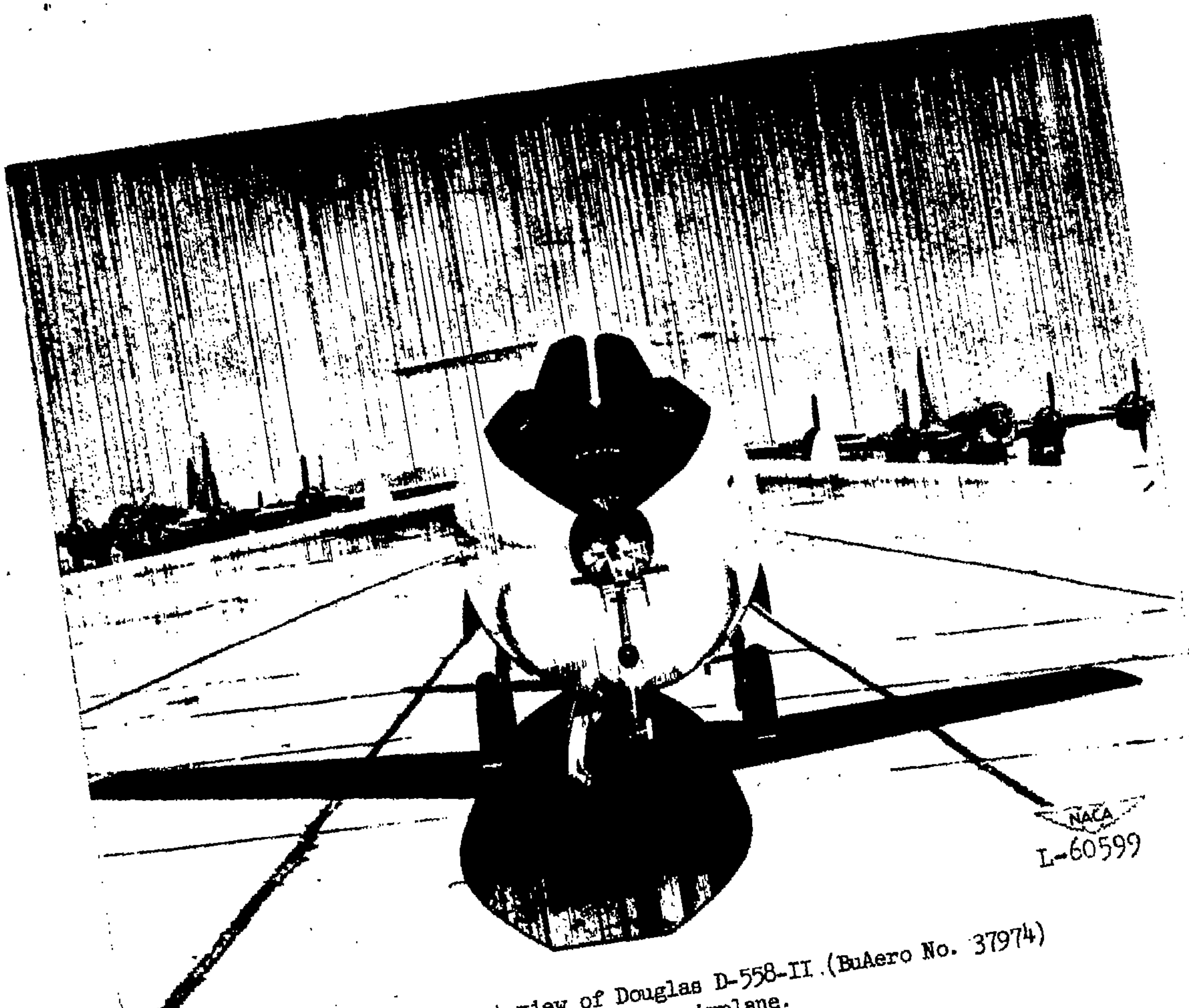

Figure 1.- Front view of Douglas D-558-II (BuAero No. 37974) research airplane.

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Figure 2.- Three-quarter rear view of Douglas D-558-II (BuAero No. 37974) research airplane.

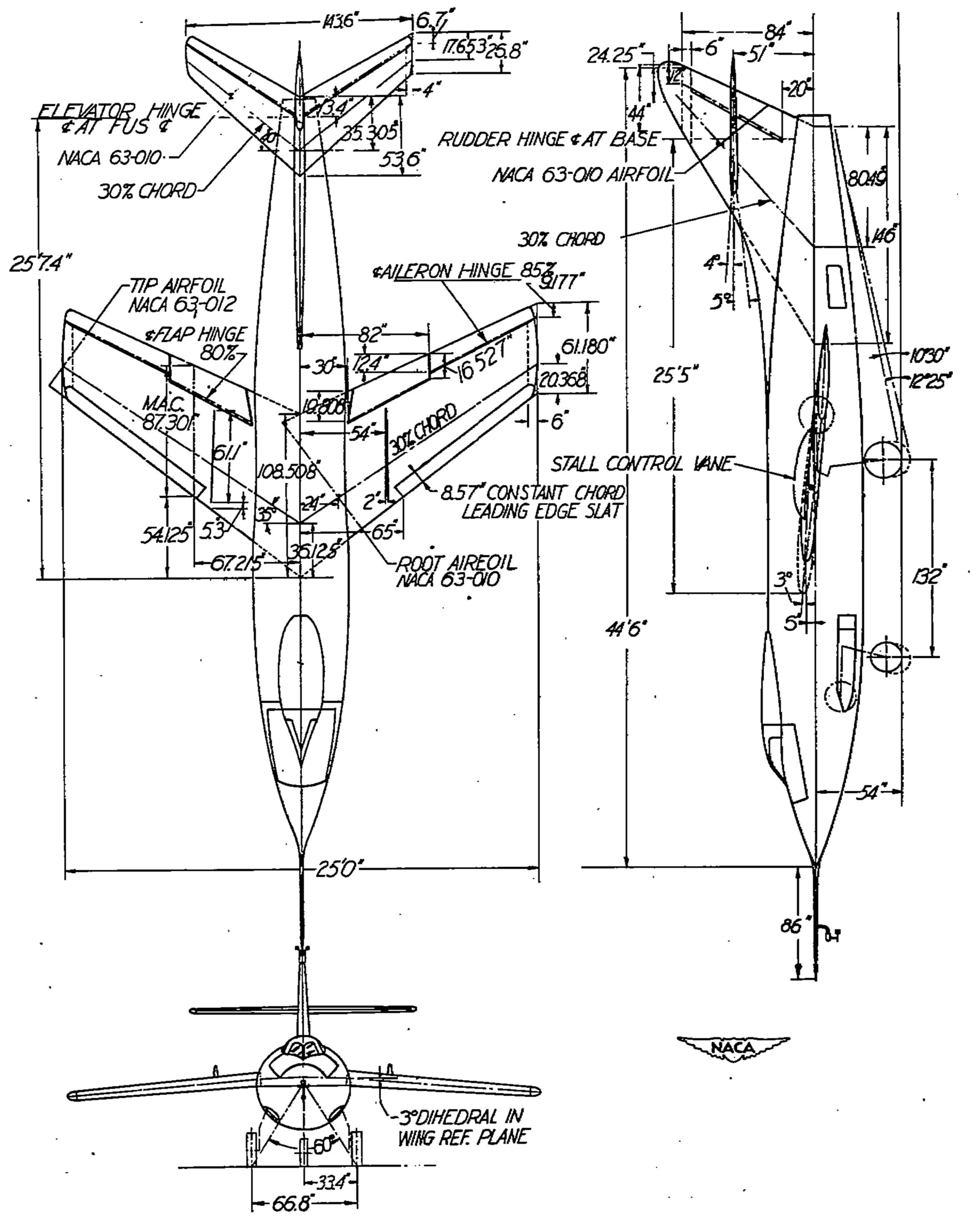

Figure 3.- Three-view drawing of the Douglas D-558-II (BuAero No. 37974) research airplane.

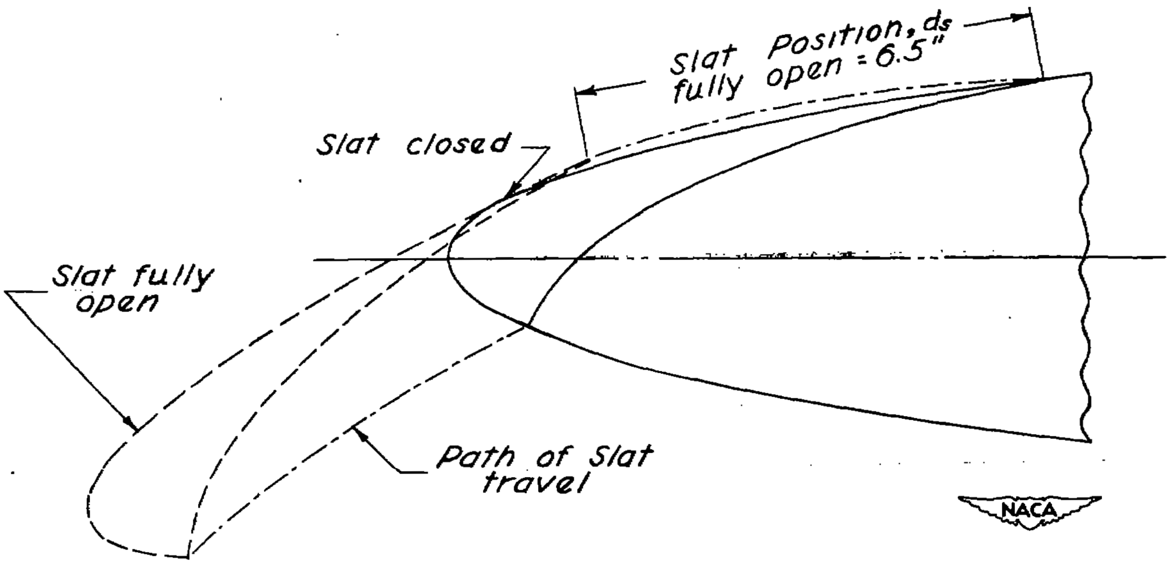

Figure 4.- Section of wing slat of Douglas D-558-II (BuAero No. 37974) research airplane perpendicular to leading edge of wing.

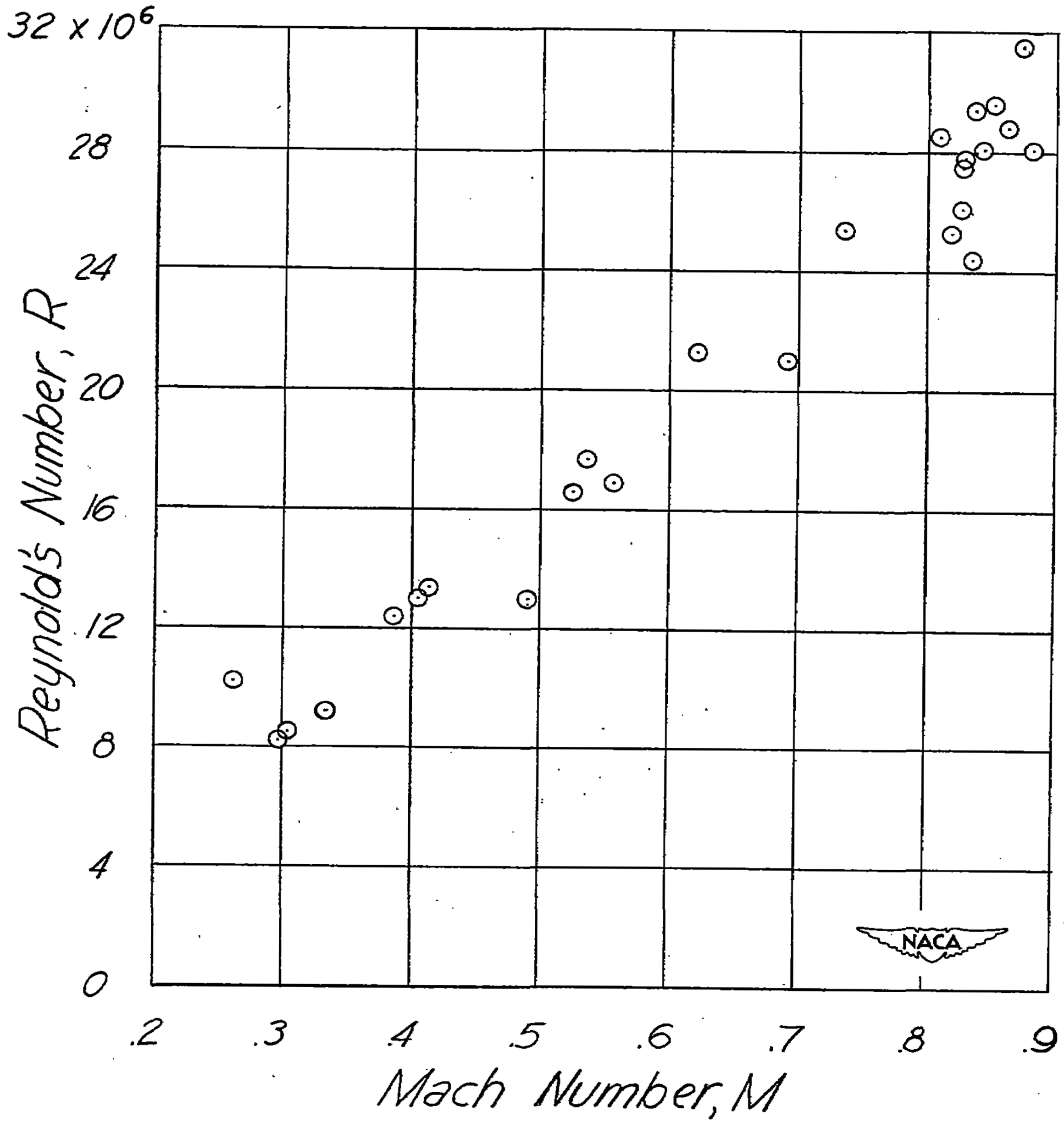

Figure 5.- Range of Reynolds number and Mach number covered in tests. D-558-II airplane.

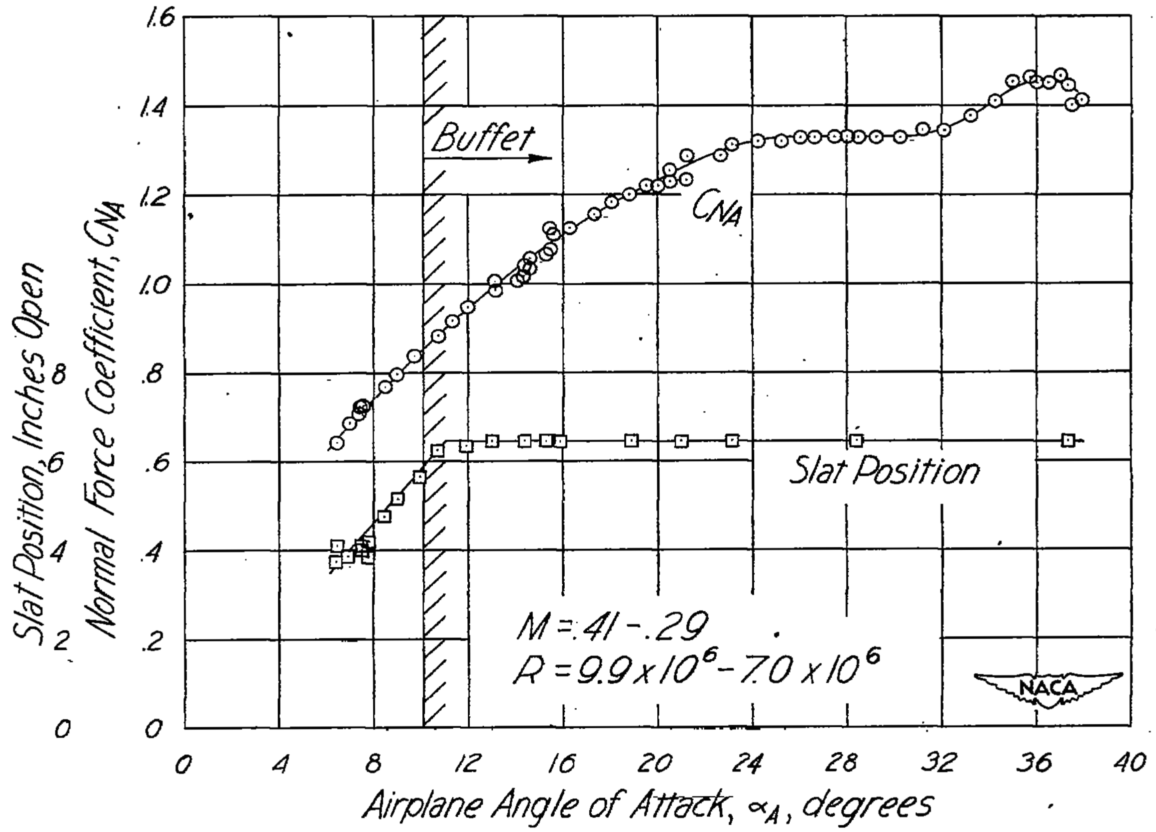

Figure 6.- Variation of airplane normal-force coefficient and slat position with airplane angle of attack. Slats unlocked. D-558-II airplane.

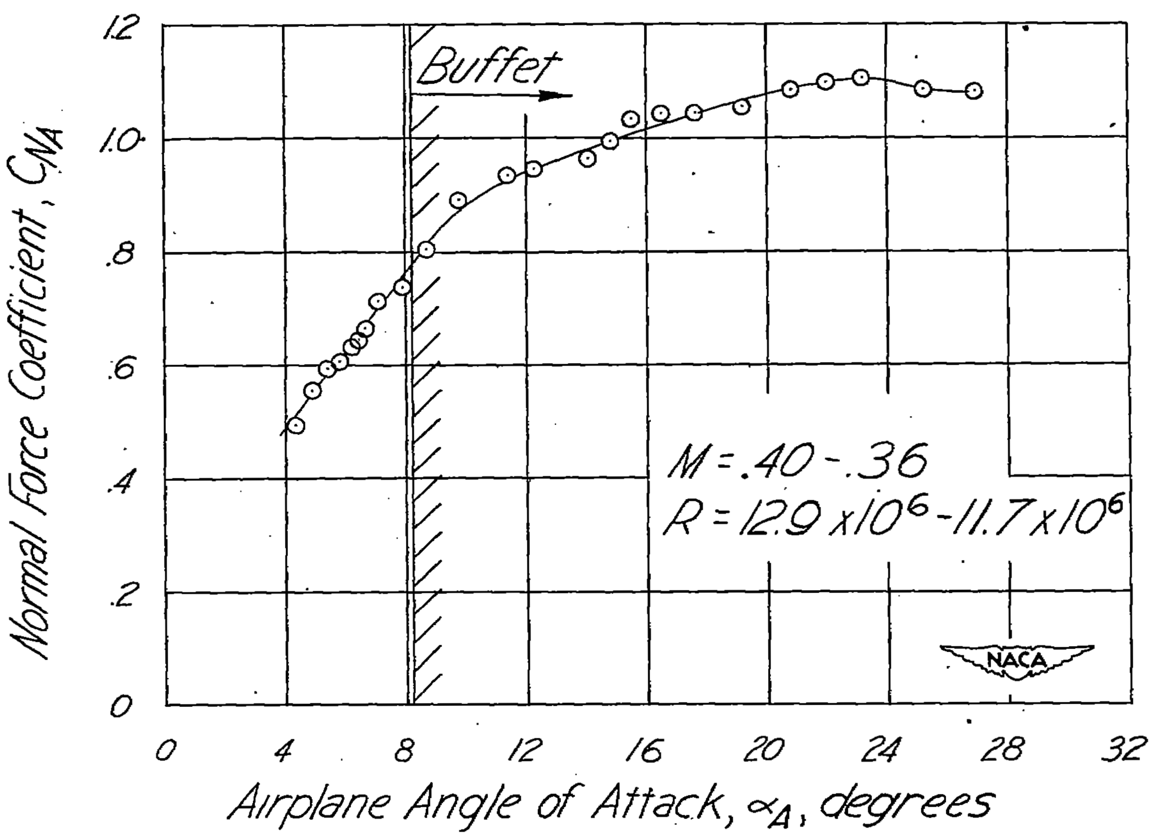

Figure 7.- Variation of airplane normal-force coefficient with airplane angle of attack. Slats closed. D-558-II airplane.

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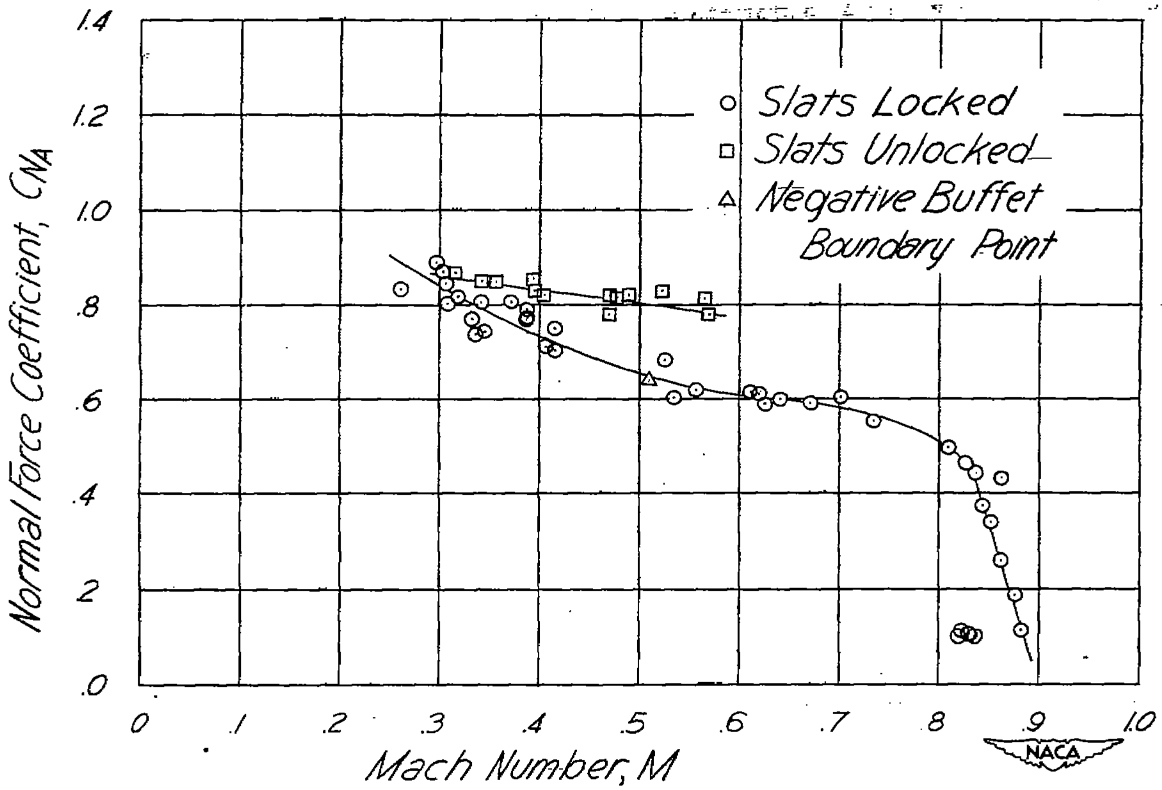
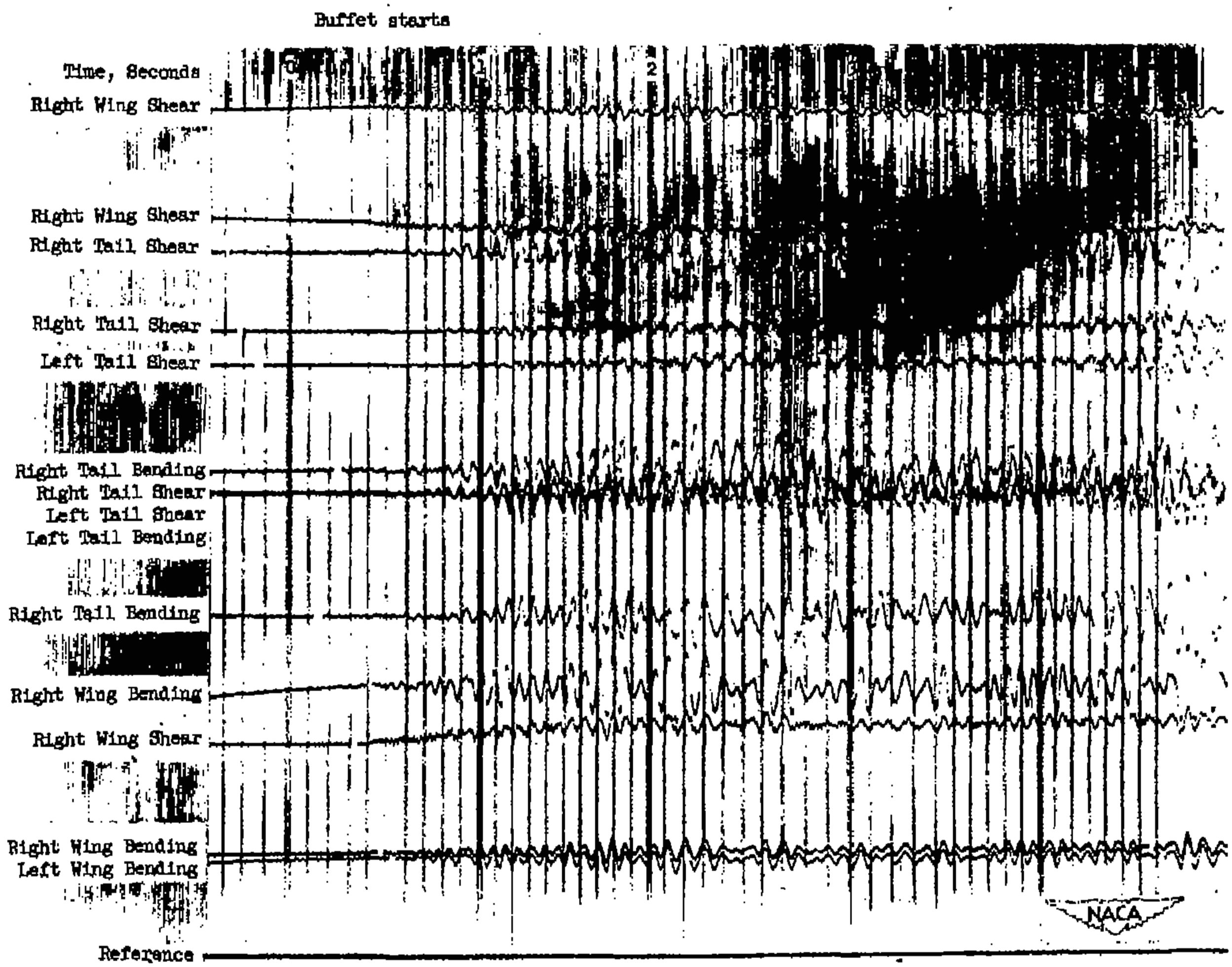
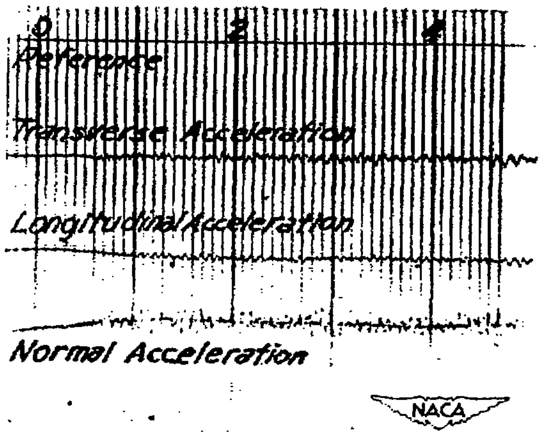


Figure 8.- Variation of airplane normal-force coefficient at which buffeting occurs with Mach number. D-558-II (37974) airplane.



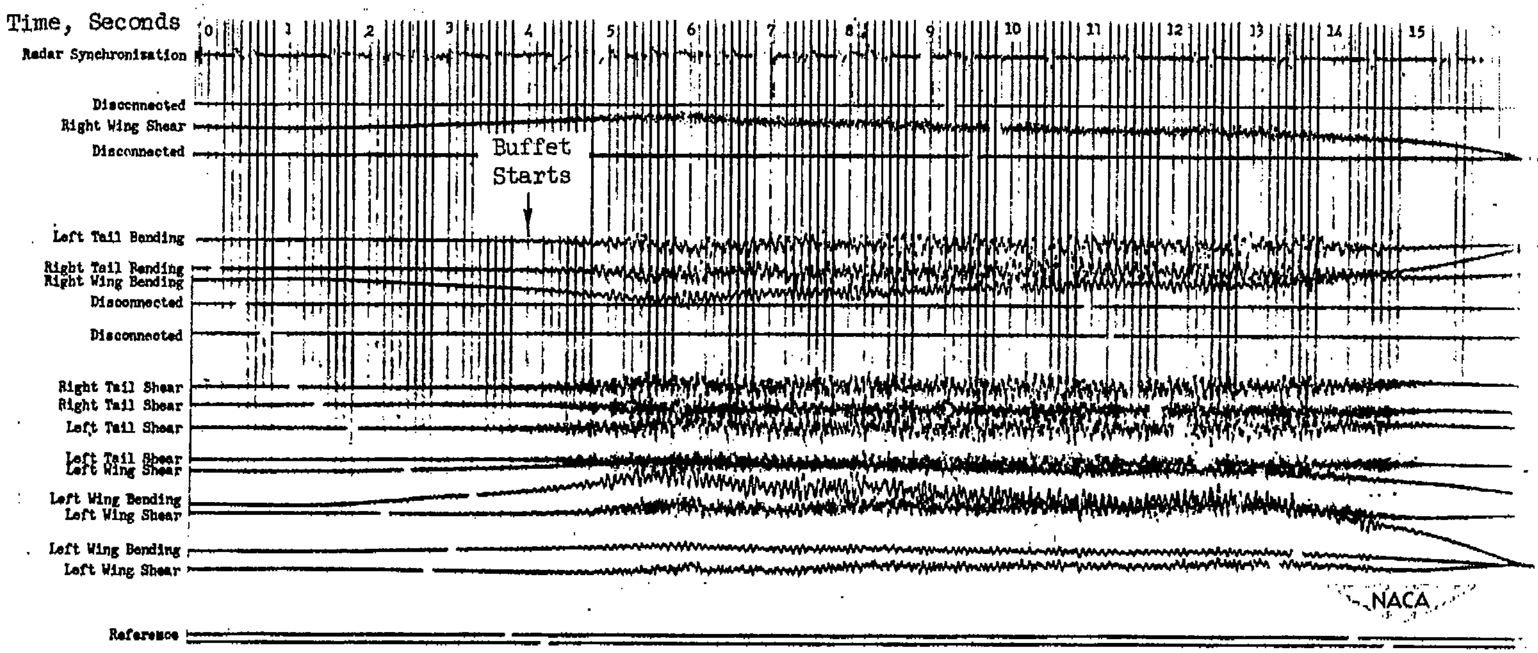
(a) Strain-gage record of 1g approach to stall $M = 0.29$; $R = 8 \times 10^6$; $q = 56$ pounds per square foot.

Figure 9.- Typical strain-gage and accelerometer records of buffeting.



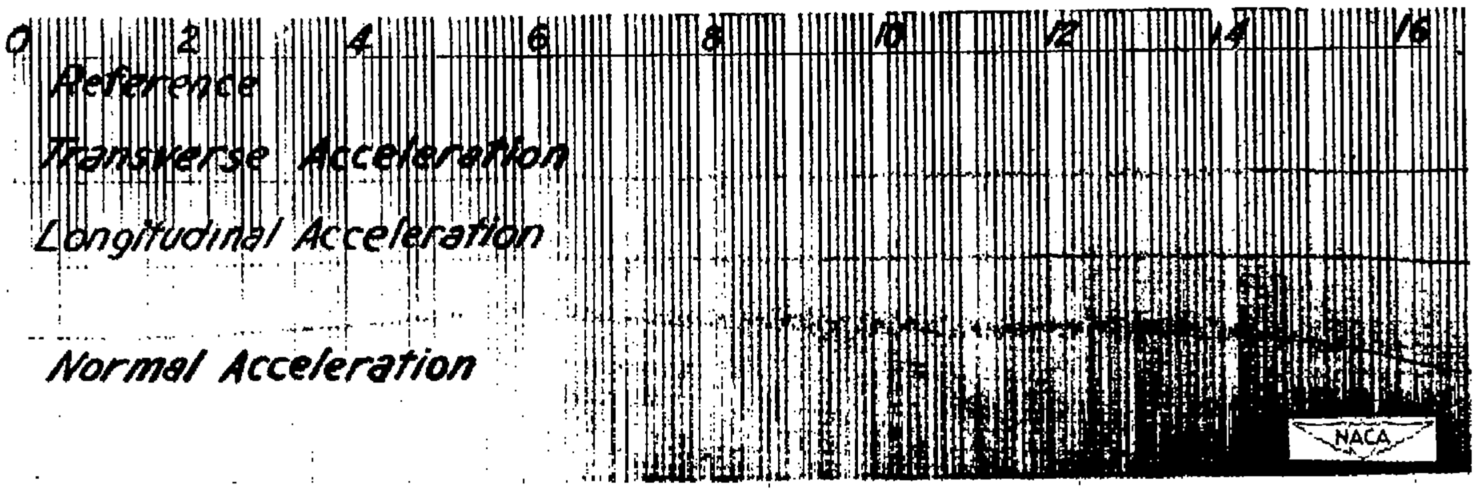
(a) Concluded. Accelerometer record.

Figure 9.- Continued.



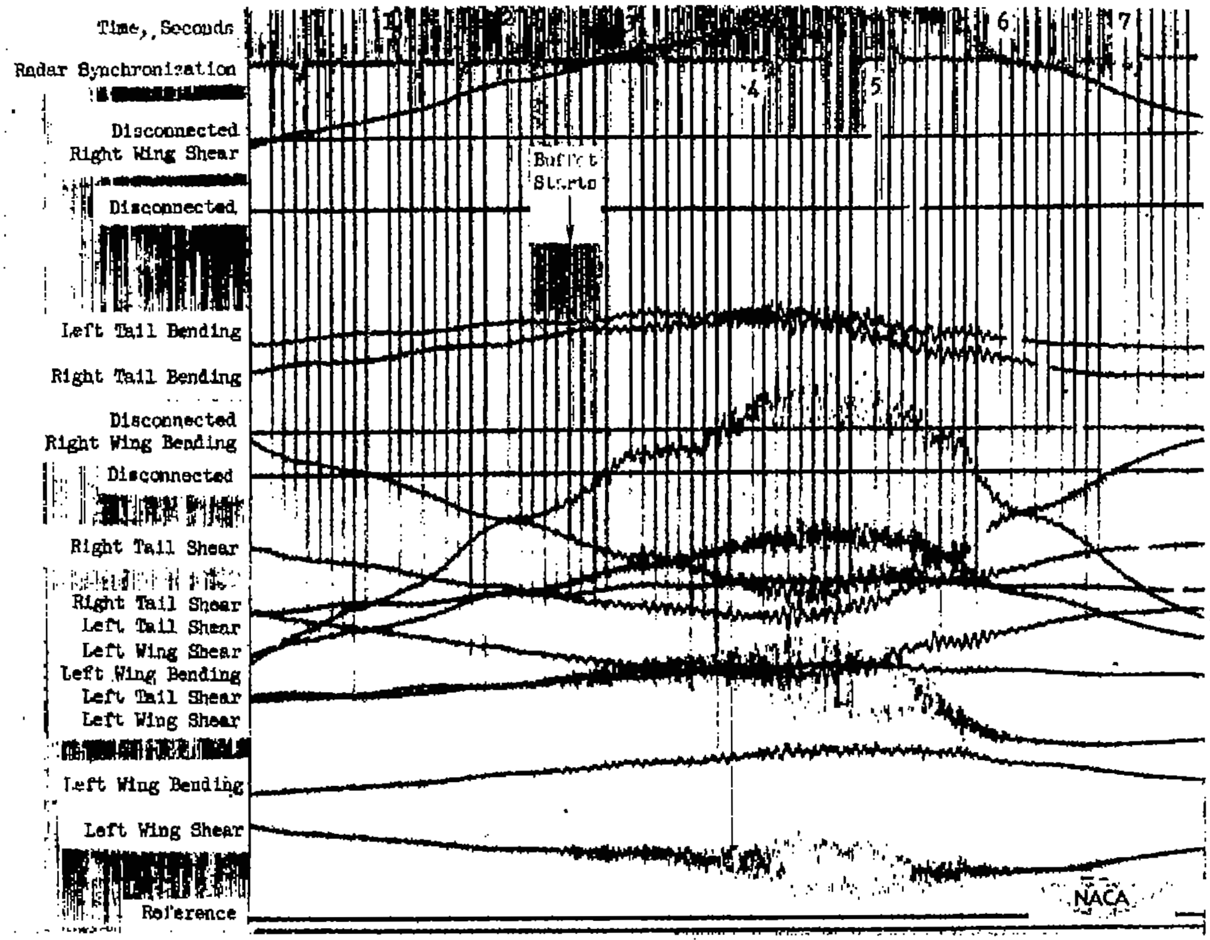
(b) Strain-gage record of low-speed turn. $M = 0.49$; $R = 11 \times 10^6$; $q = 140$ pounds per square foot.

Figure 9.- Continued.



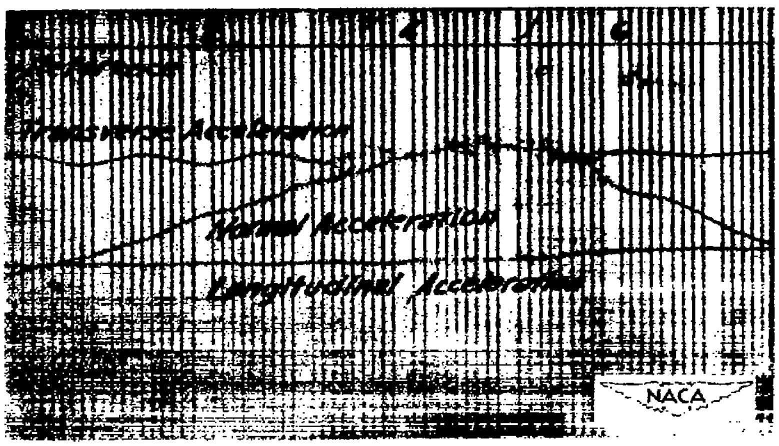
(b) Concluded. Accelerometer record.

Figure 9.- Continued.



(c) Strain-gage record of high-speed turn. M = 0.87 to 0.83; R = 31×10^6 to 28×10^6; q = 610 to 580 pounds per square foot.

Figure 9.- Continued.



(c) Concluded. Accelerometer record.

Figure 9.- Concluded.

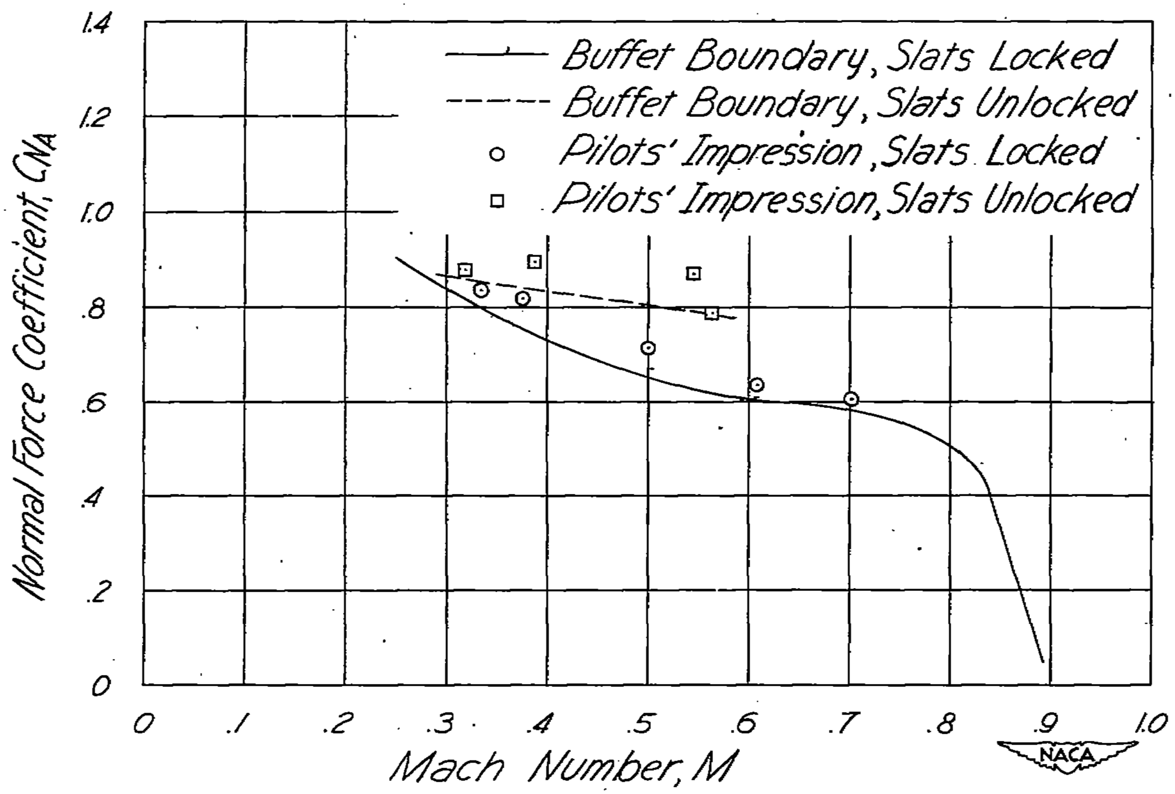


Figure 10.- Comparison between the buffet boundary as established by means of recording strain-gage and accelerometer measurements and pilot's impression of the start of buffeting. D-558-II airplane.

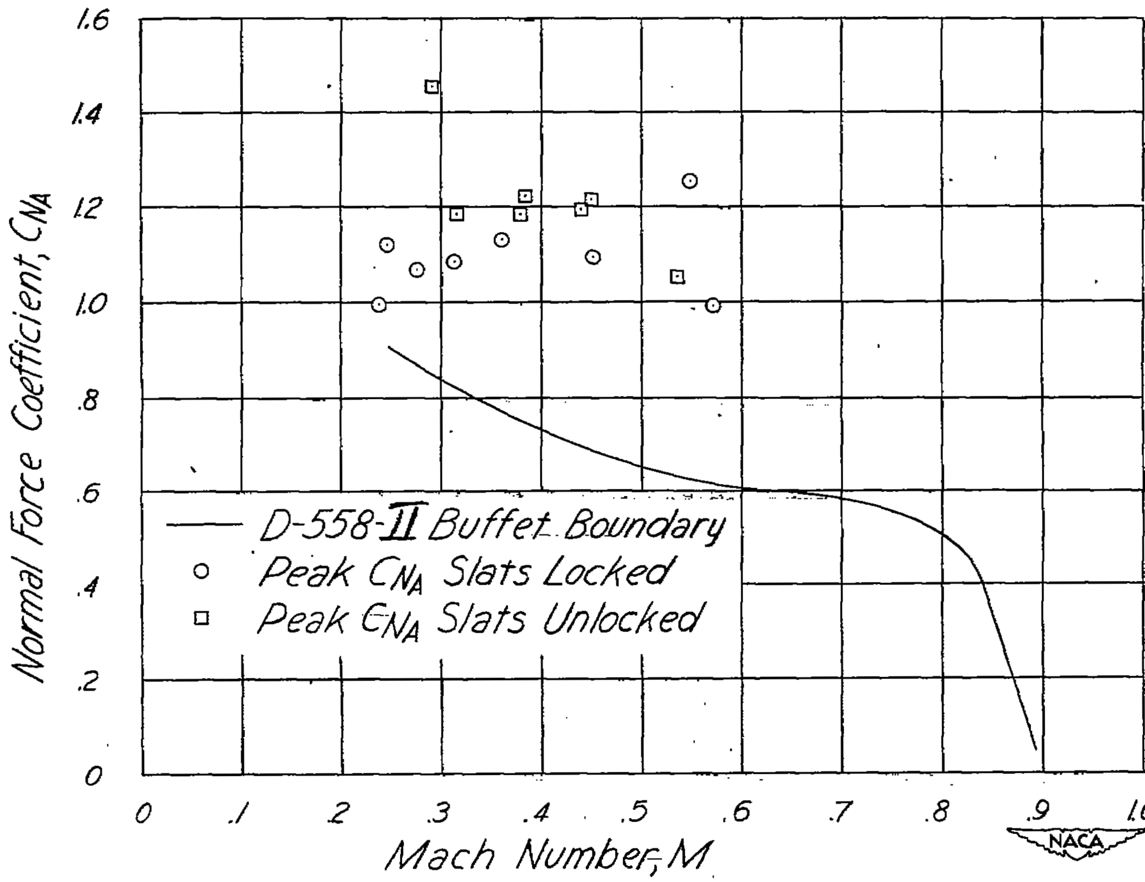


Figure 11.- Variation of peak normal-force coefficients with Mach number. D-558-II (37974) airplane.

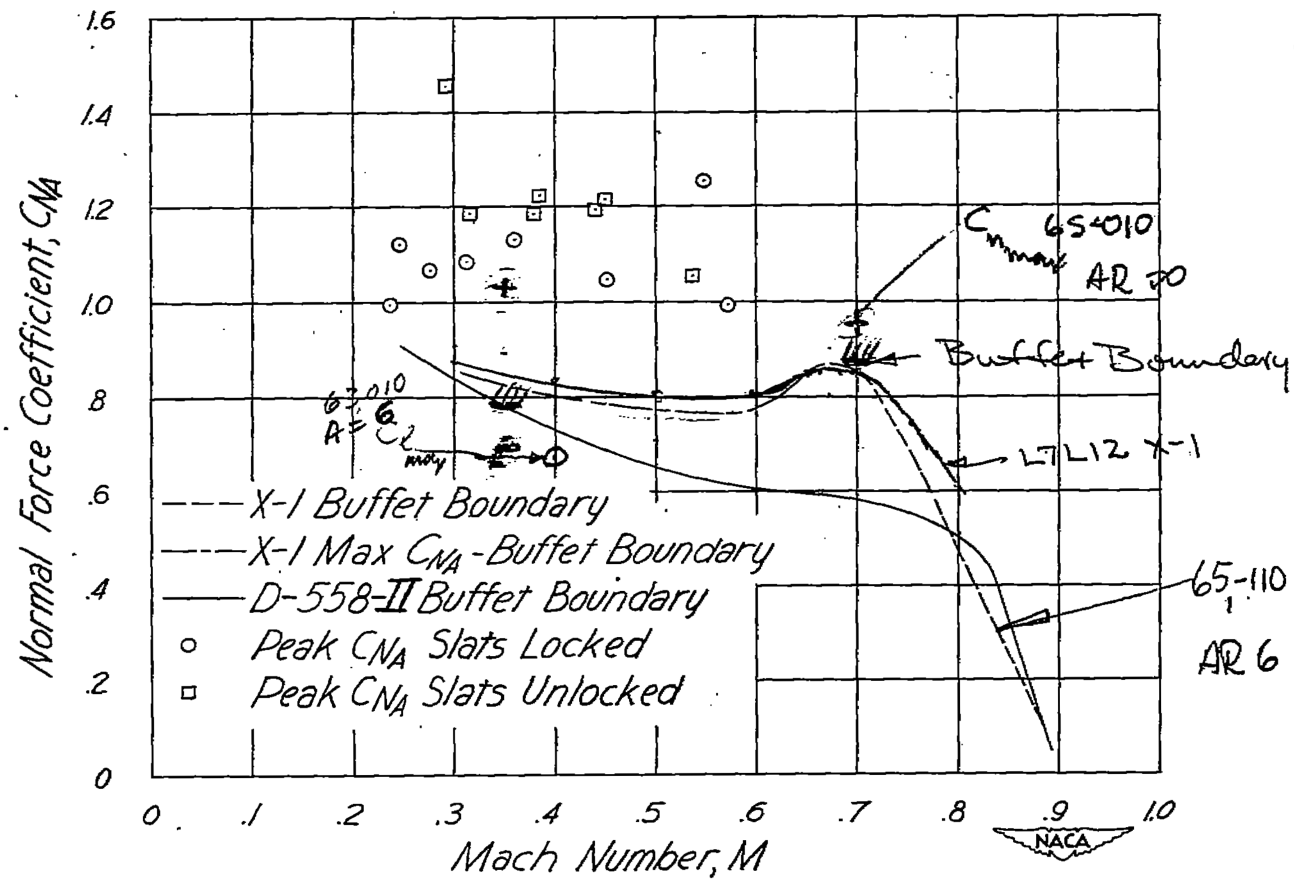


Figure 12.- Comparisons between the buffet boundaries and maximum normal-force coefficients for the D-558-II and X-1 airplanes.